INVESTIGATION OF THE EFFECTS OF ULTRASONICS ON THE DEFORMATION CHARACTERISTICS OF METALS

Prepared under US.Government,
European Research Contracts Program

Contract No. N 62558-3436
Interim Report No 1
Covering Period February 1 to April 30 1963

II.Physikalisches Institut der Universität Wien

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Investigation of the effects of ultrasonics on the deformation characteristics of metals

Abstract

A few aspects of the ultrasonic influence on the plasticity of metals are treated in this paper. It is shown that with purest zinc crystals the recovery from the cold-hardened condition (measured as the decrease of the shearing stress of the basal plane) is accelerated by an ultrasonic treatment during the period of recovery. Also the second softening mechanism - recrystallization by way of nucleation and growth of crystals - is activated at certain temperatures by ultrasonic influence, as is shown by tests with poly-crystalline specimens of commercial zinc. Both softening mechanisms are based on diffusion processes in the lattice, whose kinetics is accelerated by ultrasonic treatment under the conditions used.

1 Introduction

In 1955 BLAHA and LANGENECKER (1) observed that superposition of ultrasonics essentially facilitates the plastic deformation of zinc single crystals. Later on this effect was ascertained with single crystal specimens other than zinc (2)(3)(4)(5)(6)(7)(8). The testing of poly-crystalline specimens indicated a stress reduction by superimposed ultrasonic vibration as well (9)(10)(11).

Two stress-strain curves of a zinc single crystal without

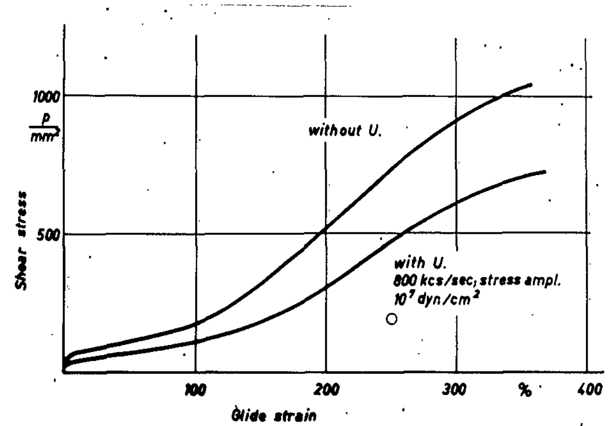

Fig.1 Stress-strain curves of a zinc crystal with and without superimposed ultrasonics (6)

and with superposition of ultrasonics during straining(fig.1) may serve as an example for the stress reducing effect of ultrasonics. In table 1 a survey is given of the results obtained from a number of zinc and cadmium crystals of various initial orientations. It becomes evident that with both metals the final glide strain (a_θ) observed with superimposed ultrasonics increases, indicating that the ultrasonic vibrations have thus facilitated plastic deformation. With cadmium crystals - in the

Table 1 Strain of metals crystals when stress is superimposed (or not) by ultrasonics (800 kcs/sec, 30W/cm^2)

χ_0	λ_0	τ_e p/mm^2 without	τ_e p/mm^2 with	a_θ % without	a_θ % with
Zn-crystals (4)					
17°	21°	688	757	383	652
36	37	938	1070	506	609
45	49	762	890	676	747
57	62	920	931	457	662
Cd-crystals (5)					
12°	20°	220	192	180	185
14	14	296	268	260	270
22	24	325	216	340	370
27	30	328	236	350	420

χ_0 = angle between wire axis and slip-plane

λ_0 = angle between wire axis and slip-direction

case of superposition of ultrasonics - the final shearing stress (τ_e) figures less, despite the higher final glide strain and with zinc crystals it exceeds the values for crystals without influence of ultrasonics.

The effects of superposition of ultrasonics on crystal plasticity is of interest for two reasons: it offers the possibility to widen our understanding of the effects of lattice defects on the behaviour of metal crystals and moreover it may lead to a technologically practicable method to facilitate the forming of metallic materials. Within the scope of an international

cooperation the two possibilities shall be examined. With the personnel and equipment available at our institute mainly fundamental experiments shall be performed on the behaviour of metal crystals and poly-crystalline specimens in static tension tests with superimposed ultrasonic stress. Futhermore studies of the closely connected question of an ultrasonic influence on recovery and recrystallization of strain hardened specimens are planned.

2 Experimental equipment

Single-crystalline specimens are produced by the CZOCHRALSKI-method of drawing from the melt. With zinc thin cylindrical crystal wires (approximately o.5 - 1.o mm diameter) are obtained without any precautions; with cadmium we were forced to protect the metal against oxidation by drawing in an Argon atmosphere.

The influence of ultrasonics on the recrystallization of metals is being examined in poly-crystalline specimens of commercial zinc("Hüttenzink" ; 1% impurities). In order to be able to observe the behaviour during recrystallization at a temperature slightly above room temperature specimens of a certain degree of strain (66%) had to be used; the degree of strain required was obtained by cold-drawing of annealed material.

Extension apparatuses of the POLANYI-type (2)(6) are available for the performance of the straining experiments. Two machines of the Sonostat type (Siemens & Reininger) and a Branson machine of the Sonifier type as transducer are at our disposal. With the former types quartz crystals are used as sound generators with a frequency of 8oo kcs/sec and a maximum capacity of 4 W/cm^2, adjustable in 9 stages. By an intermediate exponential horn the energy of the sound transferred to the crystal soldered in in the top of the horn may reach values very much higher. The Branson generator has a power output of 75 Watt and drives a lead-zirconate-titanate transducer with a frequency of 2o kcs/sec.

In the performance of the recovery and recrystallization tests the temperature has to be kept on an absolutely constant level. The specimen, therefore, is immersed in a vessel containing oil, which is connected with a thermostat guaranteeing a constancy of temperature of $\pm$ o.5^{o}C. In these cases the ultrasonic excitation is not effected by direct connection between

the specimen and the mechanical transformer, but by coupling of the transducer to the bottom of the oil vessel. An extension apparatus described in (2) was used for the observation of the recovery of single crystals, whereas microhardness tests of polycrystalline specimens after an adequate exposure to ultrasonic waves were used to examine recrystallization. The metallographic preparation of the specimens (longitudinal grinding of the cylindrical wires with a diameter of approximately 1 mm as far as nearly to the centre and subsequent electropolishing in chromic acid) was carried out before the ultrasonic treatment.

3 Results

The reports on the results obtained will be subdivided according the most important tasks: (a) influence of superposition of ultrasonics on static strain tests, (b) significance of ultrasonics for recovery, and finally (c) significance of ultrasonics for recrystallization.

3a Influence of superposition of ultrasonics on static strain tests

The influence of frequency and energy of ultrasonics is under examination. In this report, however, results cannot yet be given.

3b Significance of ultrasonics for recovery

Generally the term recovery is used for the continous approach of properties, changed by previous treatment, to the initial values. With single crystals the test conditions are simplest because there is no superposition of the effects of grain boundaries. Therefore the significance of ultrasonics for the recovery after cold straining was first of all examined with zinc single crystals. Neighbouring samples of the same crystal were subjected to a defined pre-straining (until a certain shearing stress of the basal plane-378 p/mm^2 - was reached), and subsequently they were stored at a temperature of 27 $^\circ$C in a nearly unstressed condition. After certain intervals, which in the course of the experiments became increasingly longer, the decrease in the critical shearing stress of the basal plane was determined. For this purpose after each interval the crystal was stressed merely to such an extent which made it possible to obtain the yield

strength. The recovery took place without superimposed ultrasonics as well as with ultrasonic irradiation in the oil vessel (800 kcs/sec, 4W/cm^2) during recovery. It became evident that simultaneous ultrasonic treatment accelerated the softening of the crystal. Fig.2 gives the average values of the critical basal shearing stress in function of time obtained from a series of 4 tests.

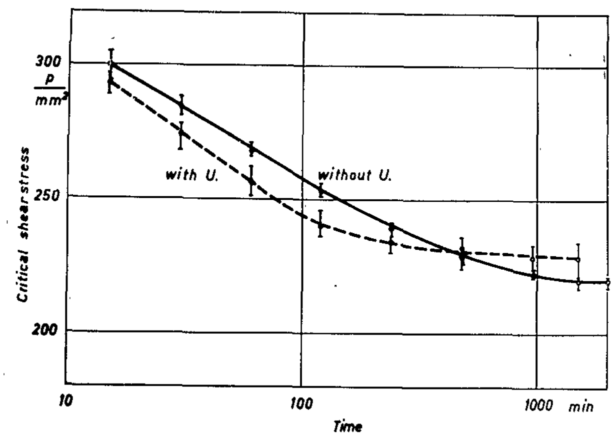

Fig.2 Recovery of deformed zinc single crystals with and without ultrasonics.

The variations observed are given in each individual case. The quicker stress reduction under the effect of ultrasonics during the recovery intervals is clearly revealed by the figures given. Under the deformation and recovery conditions chosen, the initial shearing stress of the basal plane (42 p/mm^2) is not reached; the thermal recovery((378-225)/(378-42) = 0.46) amounts to approximately 46 percent only. Whether the final values of the shearing stress obtained are the same with and without superimposed ultrasonic vibrations, or whether, as the figure indicates, the remaining strain hardening is higher with the irradiated specimens will be the subject of further examination.

3c Significance of ultrasonics for recrystallization

The ultrasonic irradiation of poly-crystalline specimens from commercial zinc which served for recrystallization tests, was effected in the oil bath mentioned above at temperatures of 50, 58, and 70°C, respectively. The results of micro-hardness

tests after annealing of varying duration at the temperatures of 50 and 58°C are illustrated in fig.3 . The unirradiated specimens show a marked period of incubation, which precedes the decrease in hardness. Obviously this corresponds to the formation of nuclei taking place before grain growth. The irradiated specimens show a short period of incubation

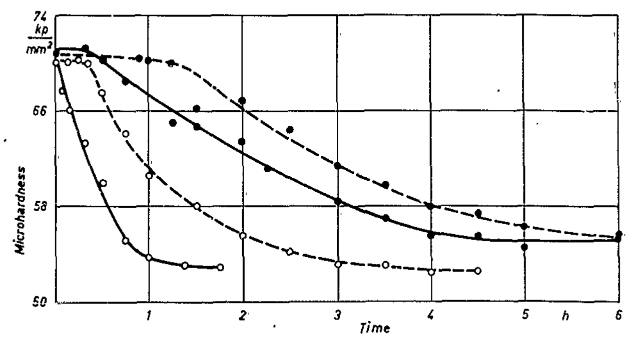

Fig.3 Recrystallization of poly-crystalline cold drawn zinc ——— with and - - - - without ultrasonics; ● 50°, ○ 58°C.

at the lower temperature only, whereas the hardness of the specimens recrystallizing at 58°C falls from the beginning of the annealing period onwards. The two hardness curves valid at the temperature of 70°C are not given in the figure. At this temperature, also with specimens with superimposed ultrasonic vibrations a decrease of hardness sets in with the beginning of the annealing period; essential differences between specimens with or without superimposed ultrasonic treatment cannot be observed.

In the same way in which the recovery of hardened single crystals from purest zinc may be activated by ultrasonic treatment, recrystallization of cold-worked polycrystalline specimens from commercial zinc is increased by ultrasonics too.

In further tests the influence of the intensity of ultrasonics on the behaviour during recrystallization shall be examined, and the question of the effects of ultrasonic influence at room temperature before recrystallization annealing shall be dealt with.

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